CTIPe Neutral Density Results and Metrics

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Coupled Thermosphere Ionosphere Plasmasphere Electrodynamics Model (CTIPe)

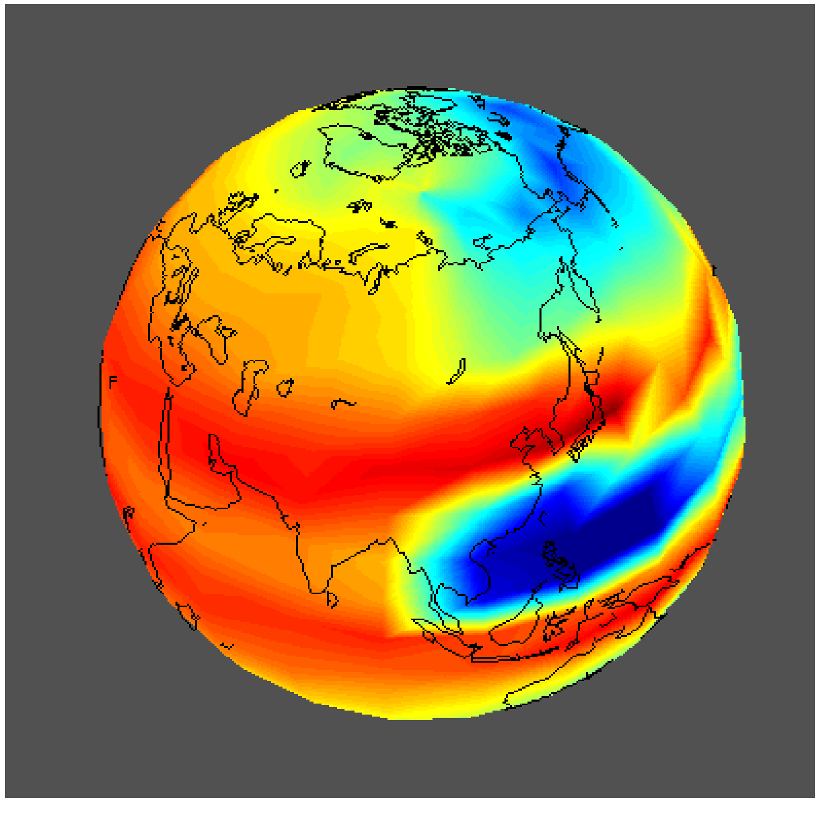
• Global thermosphere 80 - 500 km, solves momentum, energy, composition, etc. Vx, Vy, Vz, Tn, O, O2, N2, … Neutral winds, temperatures and compositions are solved self consistently with the ionosphere (Fuller-Rowell et al., 1996);

• High latitude ionosphere 80 -10,000 km, solves continuity, momentum, energy, etc. O+, H+, O2+, NO+, N2+, N+, Vi, Ti, …. (open flux tubes);

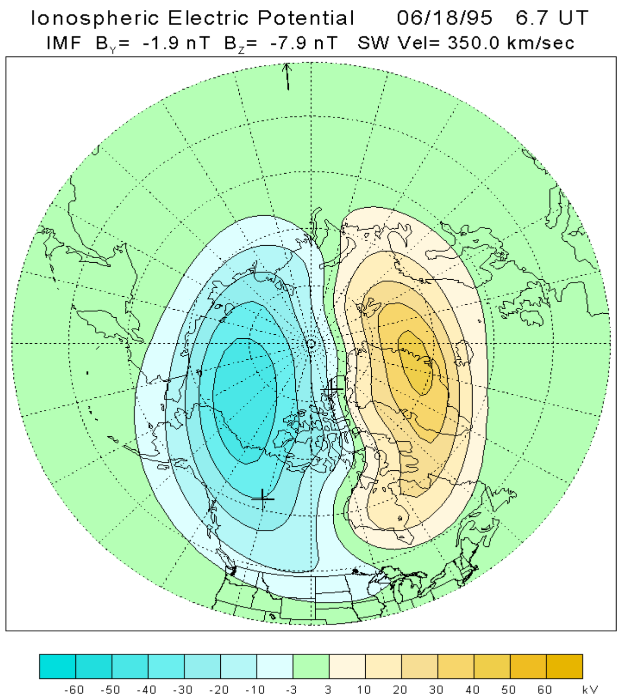
• Plasmasphere, and mid and low latitude ionosphere, closed flux tubes to allow for plasma to be transported between hemispheres (Millward et al., 1996) ;

• Self-consistent electrodynamics (electrodynamics at mid and low latitudes is solved using conductivities from the ionospheric model and neutral winds from the neutral atmosphere code);

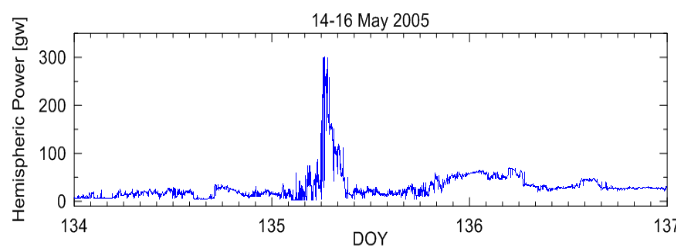
• Forcing: solar UV and EUV, Weimer electric field, TIROS/NOAA auroral precipitation, tidal forcing.

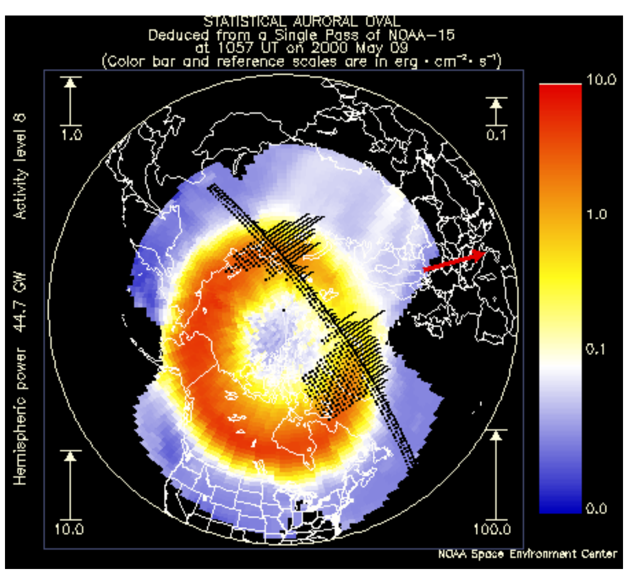


CTIPe Magnetospheric Forcing



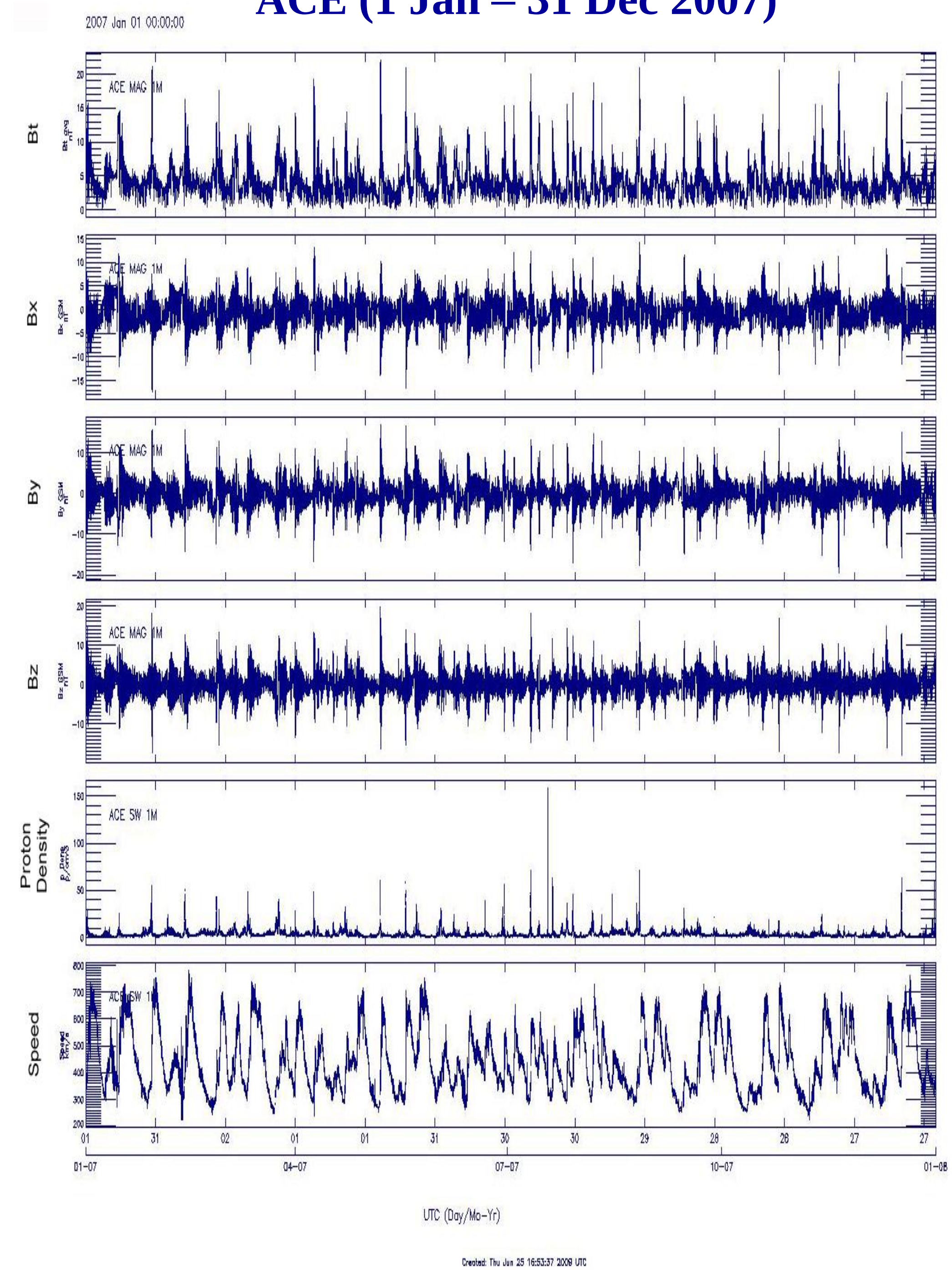
<u>Plasma convection:</u>
patterns driven by Weimer 2005 using ACE/DSCOVR data (IMF, SW vel., SW den.), 1 min. input (SWPC database).





<u>Particle precipitation:</u>
patterns driven either by power index TIROS/NOAA auroral precipitation or derived from ACE solar wind and IMF data.

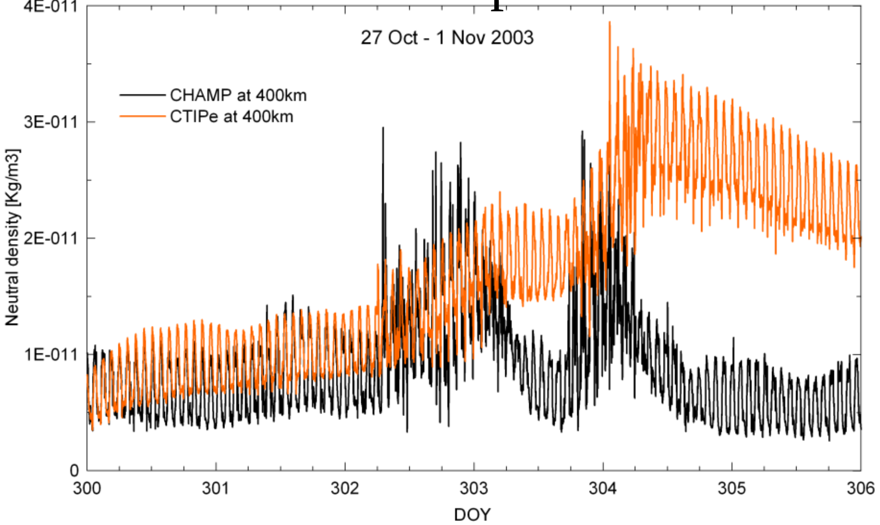
ACE (1 Jan – 31 Dec 2007)



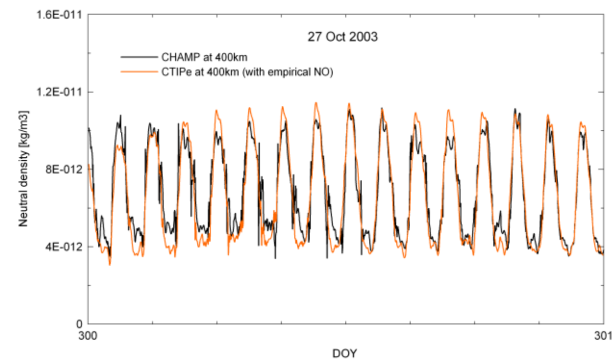
CHAMP x CTIPE: 27 Oct - 01 Nov 2003

Halloween Storm (2003)

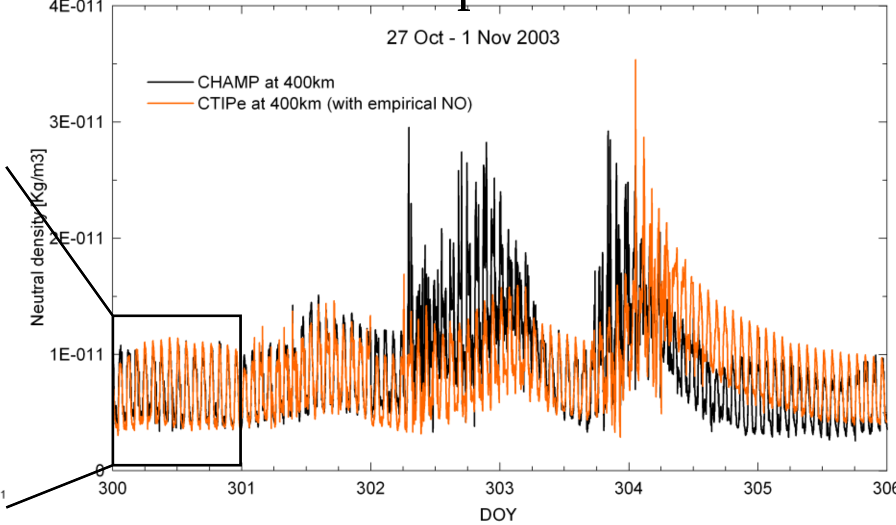
Before empirical NO



CTIPe is sampled along the CHAMP orbit



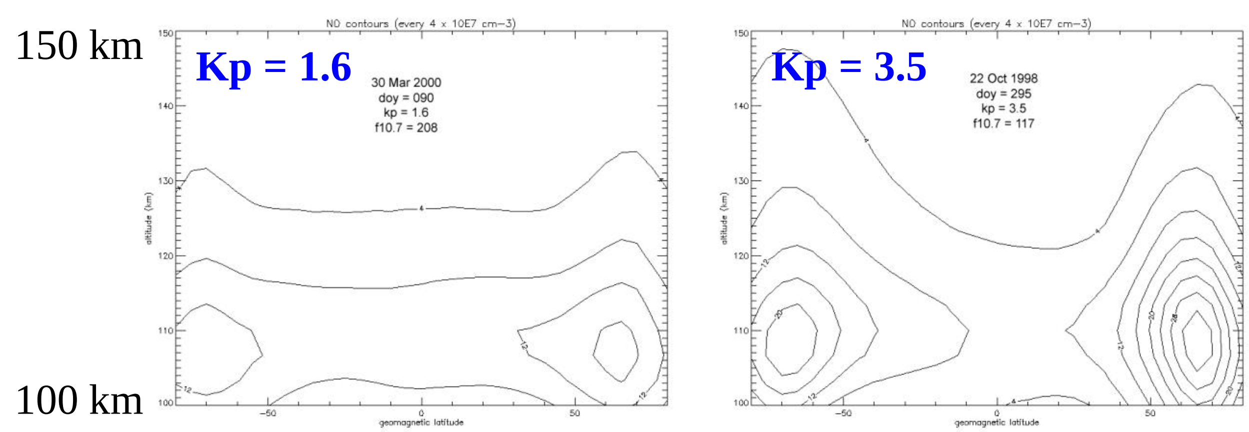
After empirical NO



Empirical NO model: Marsh et al. 2004

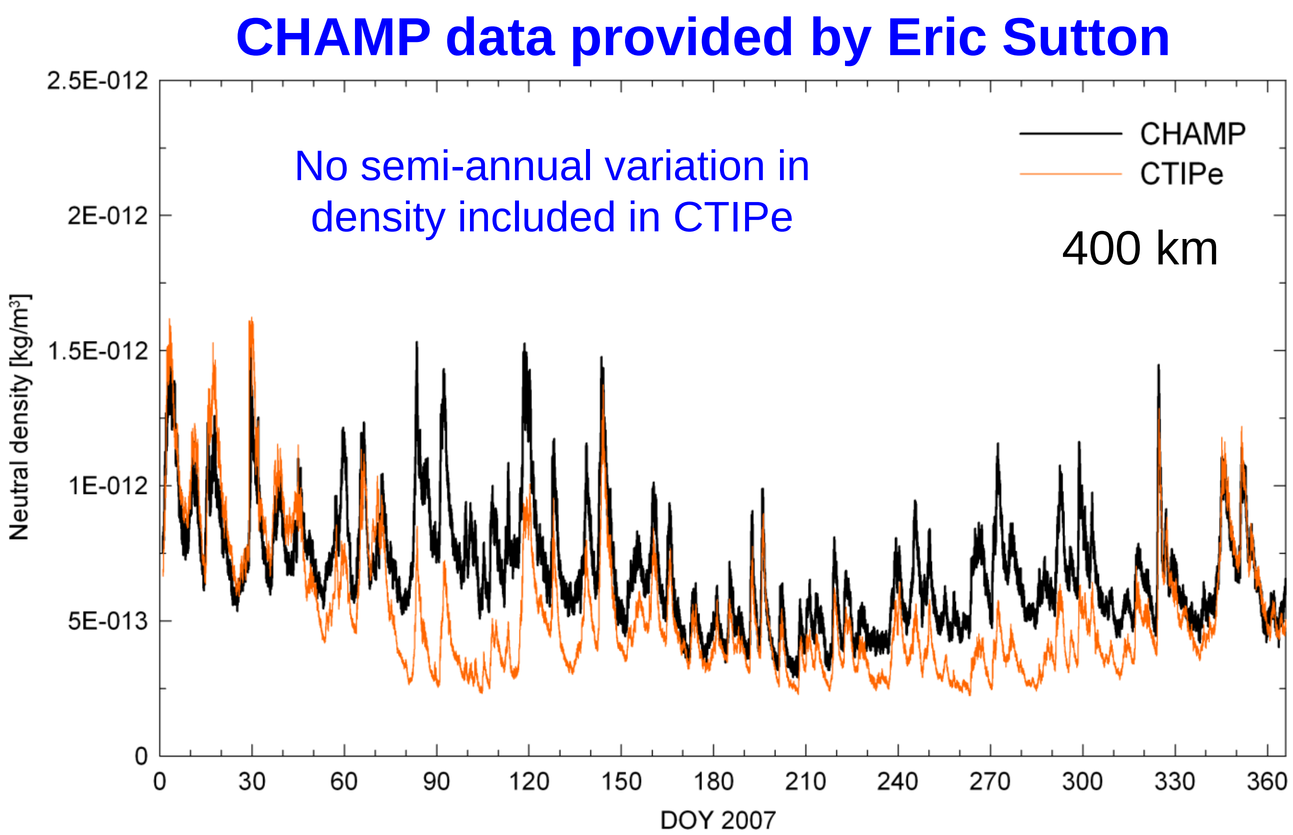
- Based on over 2.5 years of measurements from the Student Nitric Oxide Explorer (SNOE) scientific satellite
- Lower thermosphere (100-150km)
- EOFs
- Dependent on EUV, season, auroral activity, height, and latitude

NO Contours



Nitric Oxide (NO) emission at 5.3 µm acts as a "natural thermostat" allowing the atmosphere to rapidly shed energy through radiation and thereby recover from the effects of a solar or geomagnetic storm on a relatively short timescale (Mlynczak et al., 2005).

2007 CHAMP/CTIPe Orbit Average Comparisons

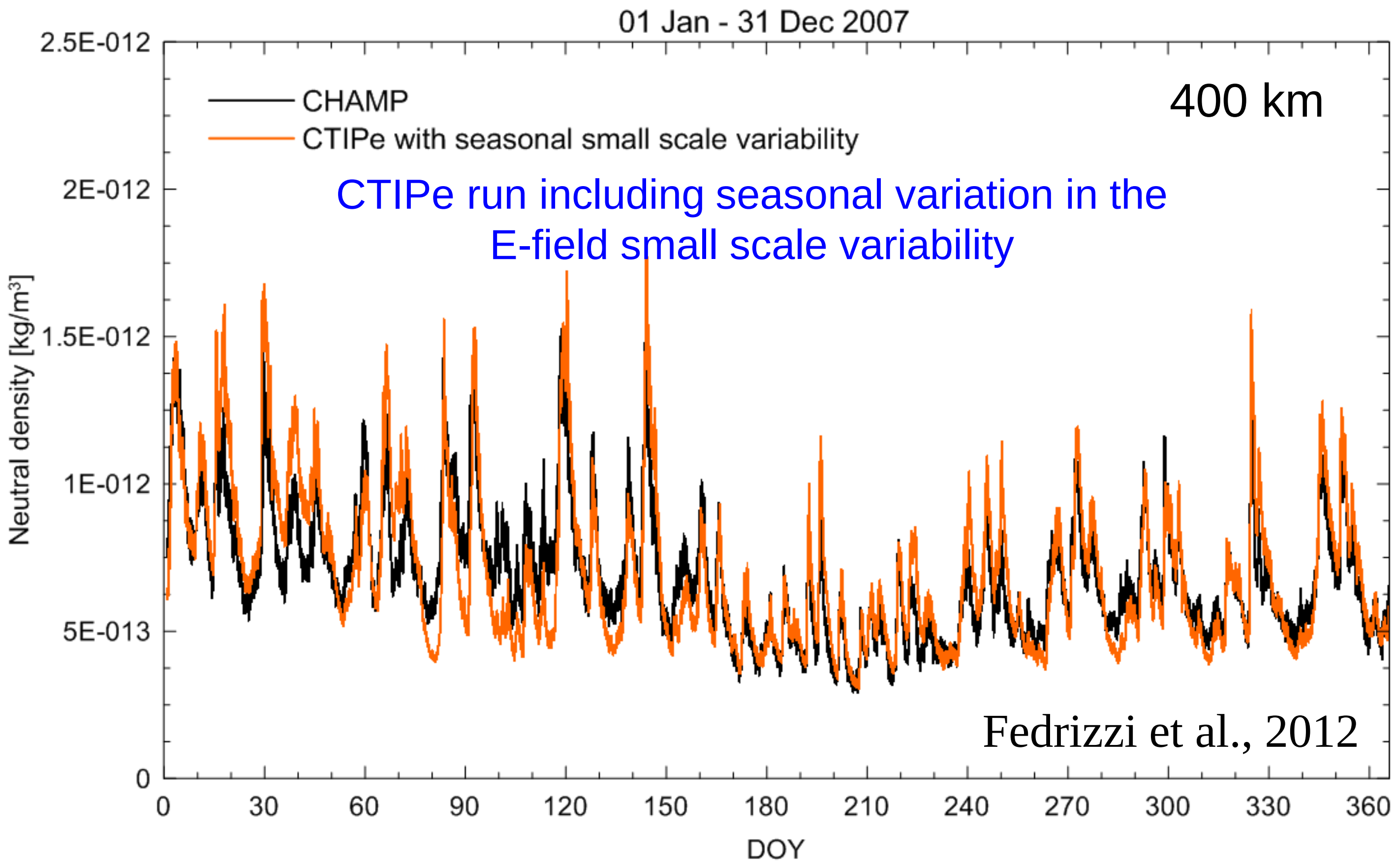


Some of these mechanisms were not included in this CTIPe model version, and it is possible that a combination of these effects (and others listed by Qian et al., 2009) could be responsible for the semi-annual variation in density.

<u>Possible Mechanisms for Semi-Annual Variation</u>:

- Seasonal variation in eddy diffusivity in the upper mesosphere and lower thermosphere regions due to gravity wave breaking (Qian et al., 2009)
- Thermospheric spoon mechanism associated with the global scale interhemispheric circulation at solstice (Fuller-Rowell, 1998)
- Asymmetry in conductivity distribution at solstice due to inequality of solar radiation between hemispheres (e.g, Lyatsky et al., 2001)
- Semi-annual variation in geomagnetic activity peaking at equinoxes (Russell and McPherron, 1973)
- Conduction mode oscillation of the thermosphere forced by the semi-annually varying Joule heating at high latitudes (Walterscheid,1982)

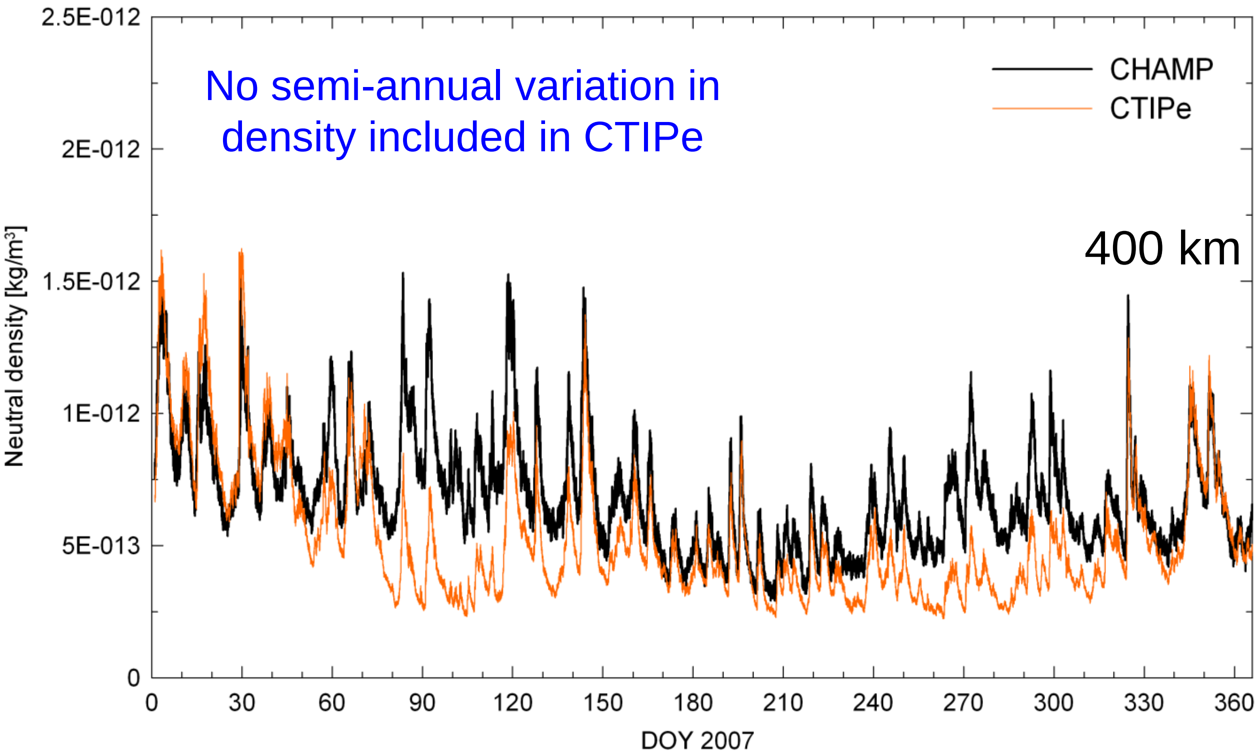
2007 CHAMP/CTIPe Orbit Average Comparisons (cont'd)

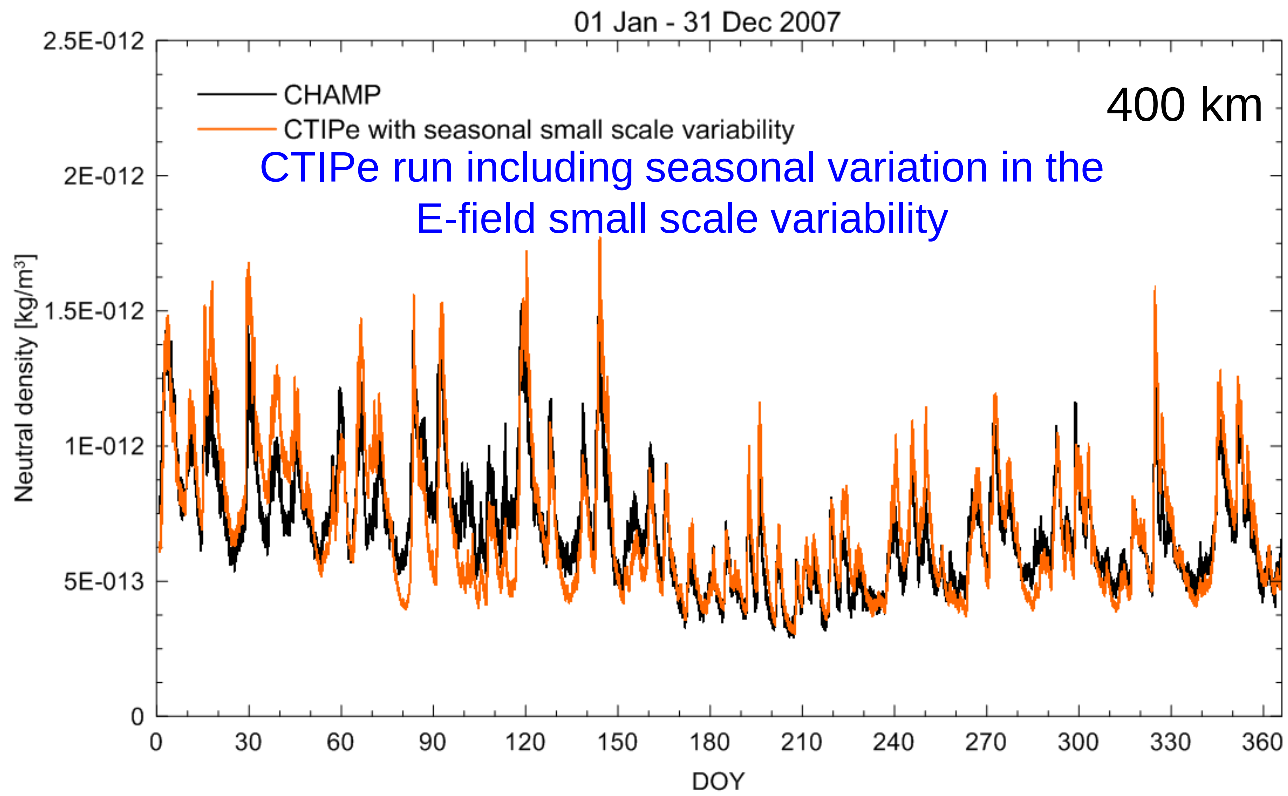


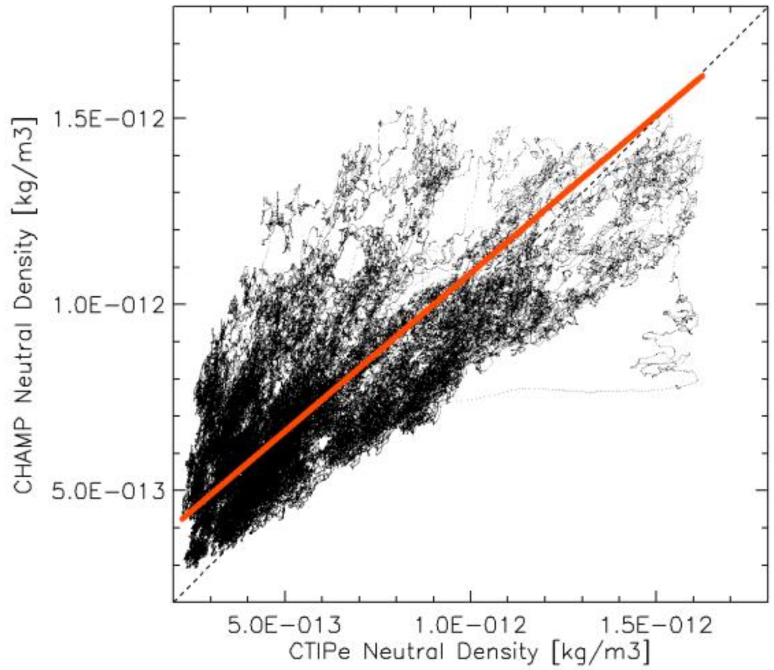
- Main purpose of this study was to simulate the model response to short-period variations in geomagnetic activity during the year.
- To accommodate this goal the semi-annual variation of neutral density in CTIPe has been removed by introducing a semi-annual variation in electric field small-scale variability.

- Electric fields can directly change Joule heating by varying the ion convection at high-latitudes (Deng and Ridley, 2007). An increase in Joule heating raises the neutral temperature, which enhances the neutral density at constant heights.
- Electric field variability changes the distribution of Joule heating significantly, and can introduce interhemispheric asymmetries (Codrescu et al., 1995, 2000).
- Previous studies have identified a significant seasonal dependence in the magnitudes of small-scale electric field variability in DE-2 (e.g., Golovchanskaya, 2007; Matsuo and Richmond, 2008) and SuperDARN data (Cousins and Shepherd, 2012).

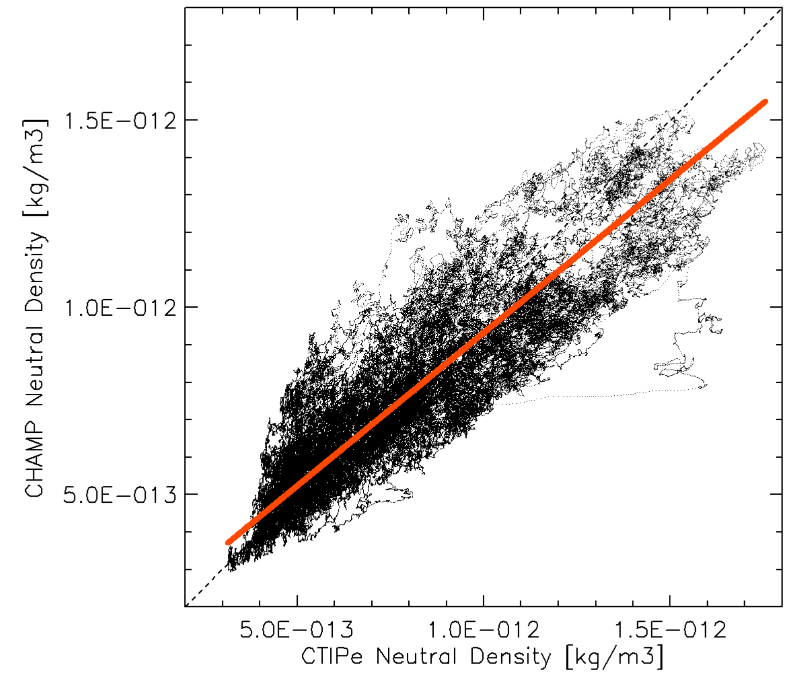
2007 CHAMP/CTIPe Orbit Average Comparisons (cont'd)







R= 0.73
RMSE= 0.31
BIAS= 0.23
SD= 0.21



R= 0.88
RMSE= 0.17
BIAS= -0.017
SD= 0.17

Metrics

- **IDL post-processing** (standard IDL functions)

- **R**: correlation coefficient is a measure of the degree of linear relationship between two variables.

  R = CORRELATE$(Model, Obs)$

- **RMSE**: root mean square error is a quadratic scoring rule which measures the average magnitude of the error (i.e., the difference between values predicted by a model and the values actually observed).

  RMSE = $\sqrt{(\sum(Obs - Model/Obs)^2)/N}$

- **BIAS**: determines whether results are consistently too high or too low relative to a given actual value of the measured or estimated variable.

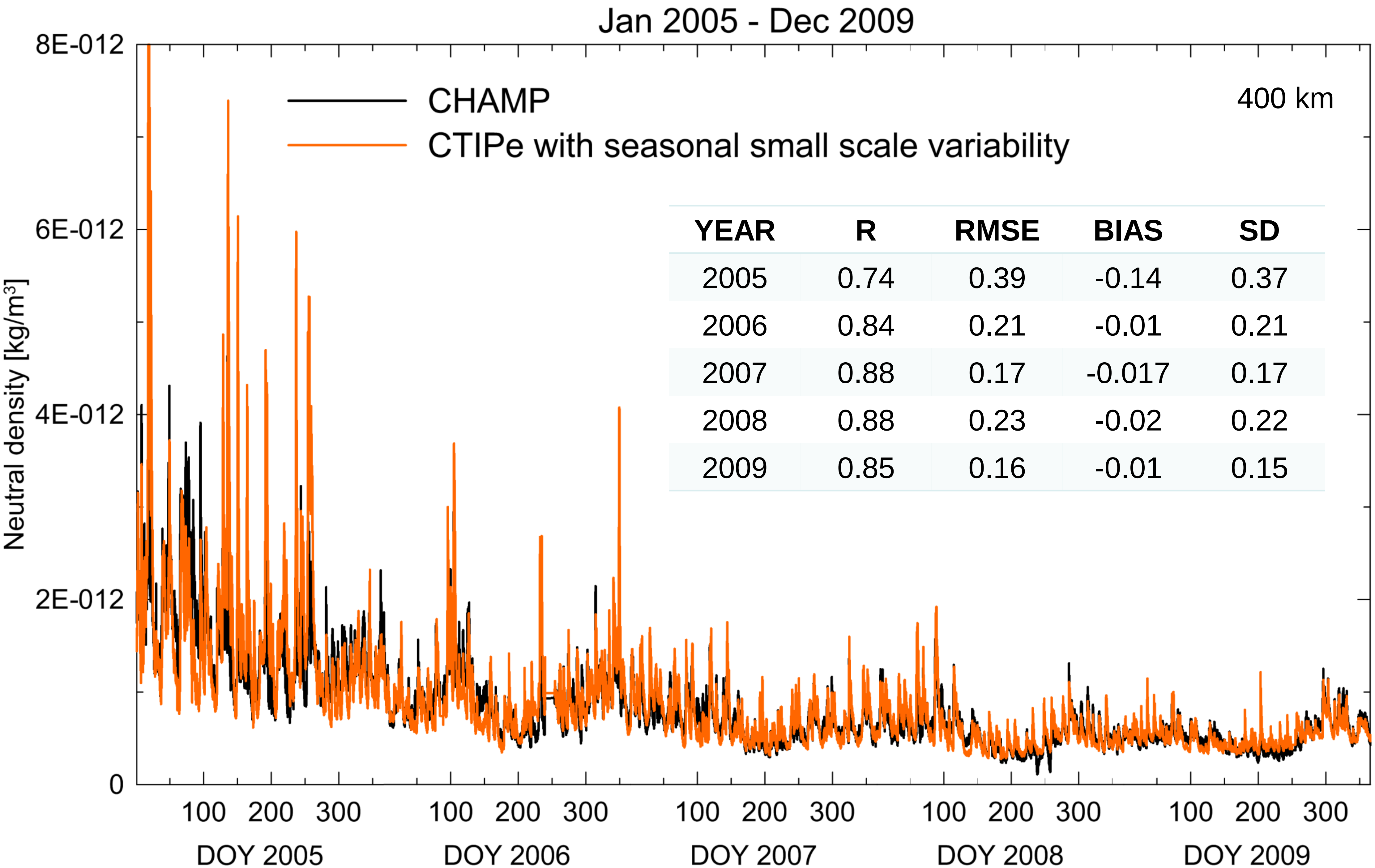
  B = $\left(\overline{Obs} - \overline{Model}\right)/\overline{Obs}$

- **SD**: standard deviation measures the dispersion of a set of data from its mean value.

  SD = STDDEV$((Obs - Model)/Obs)$

- **RMSE^2 = BIAS^2 * SD^2**

2005-2009 CHAMP/CTIPe Orbit Average Comparisons

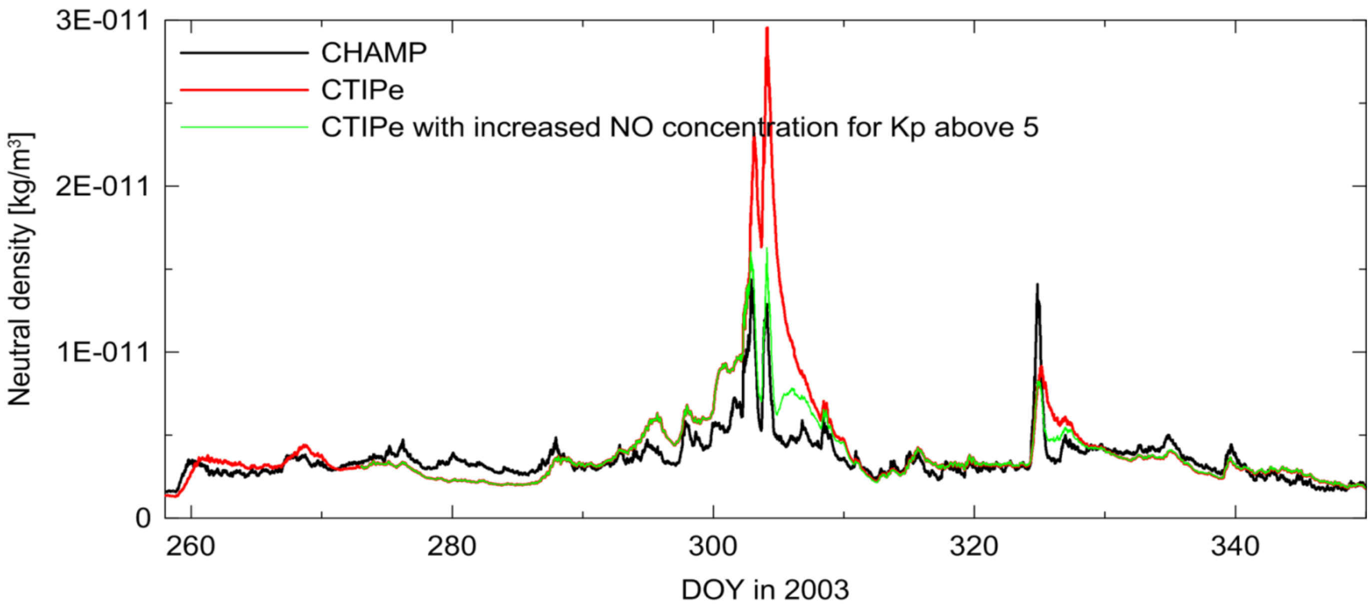


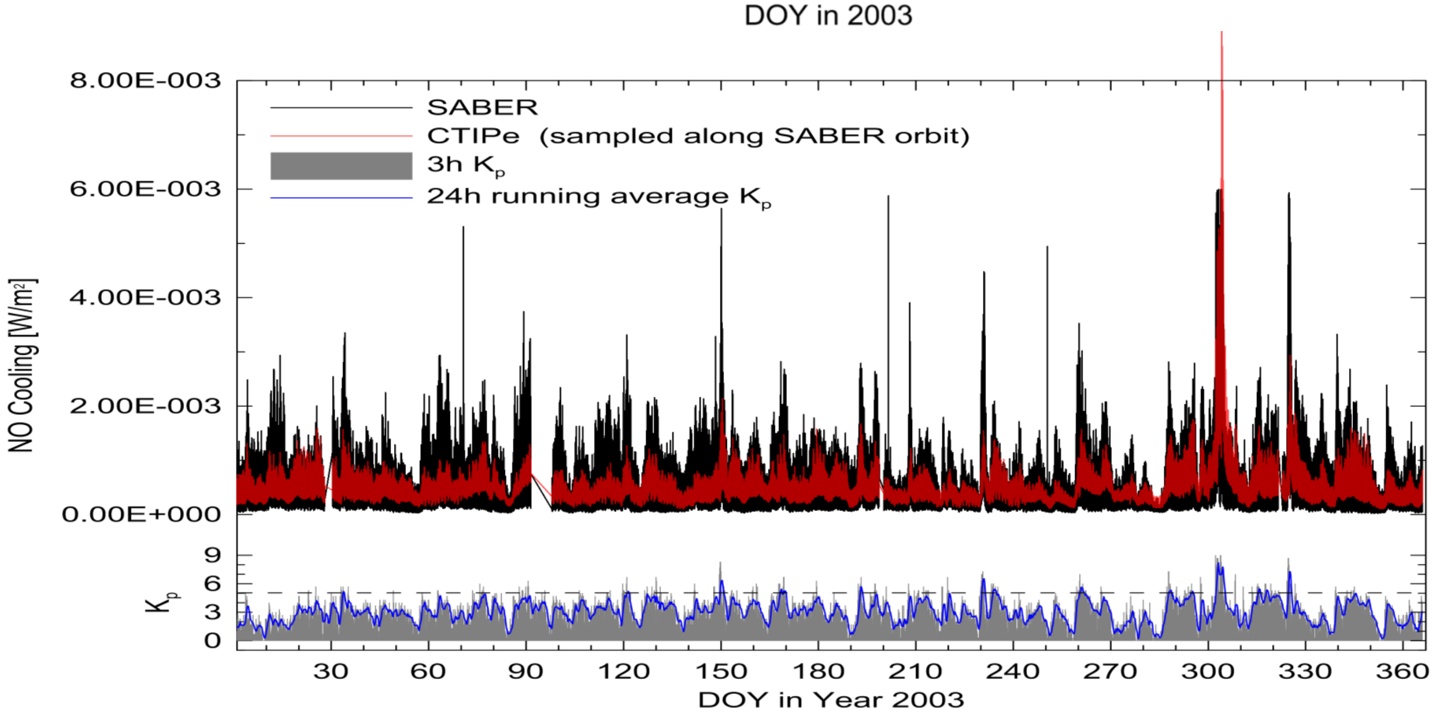
YEAR	R	RMSE	BIAS	SD
2005	0.74	0.39	-0.14	0.37
2006	0.84	0.21	-0.01	0.21
2007	0.88	0.17	-0.017	0.17
2008	0.88	0.23	-0.02	0.22
2009	0.85	0.16	-0.01	0.15

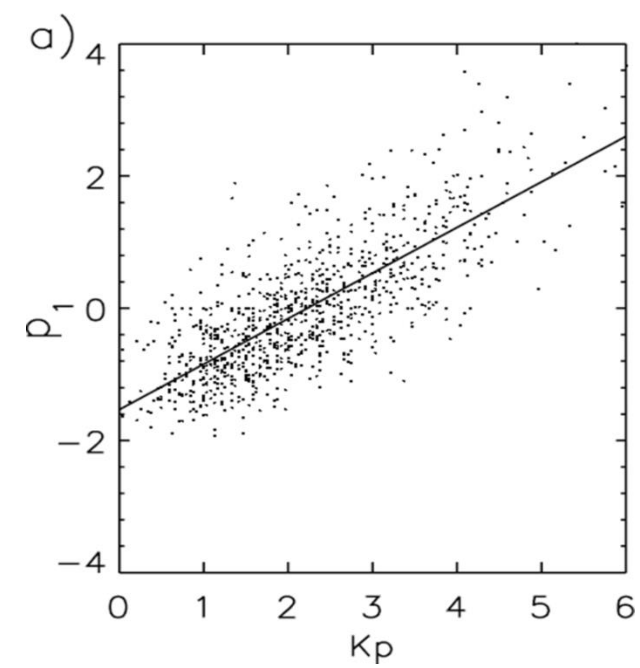
CHAMP data version 2.3 provided by Eric Sutton

NO Cooling and Neutral Density Response

- Test the possibility of insufficient NO cooling in CTIPe thermosphere during large storms -> increased NO concentration for $K_p > 5$.
- NOEM empirical model (Marsh et al., 2004) is derived from observations when K_p conditions rarely dipped below K_p 0.5 or exceeded 5. The model originally uses a linear scaling/extrapolation between K_p 5 and 9.
- The introduction of a new scaling factor in NO concentration for $K_p > 5$ has improved CTIPe results.

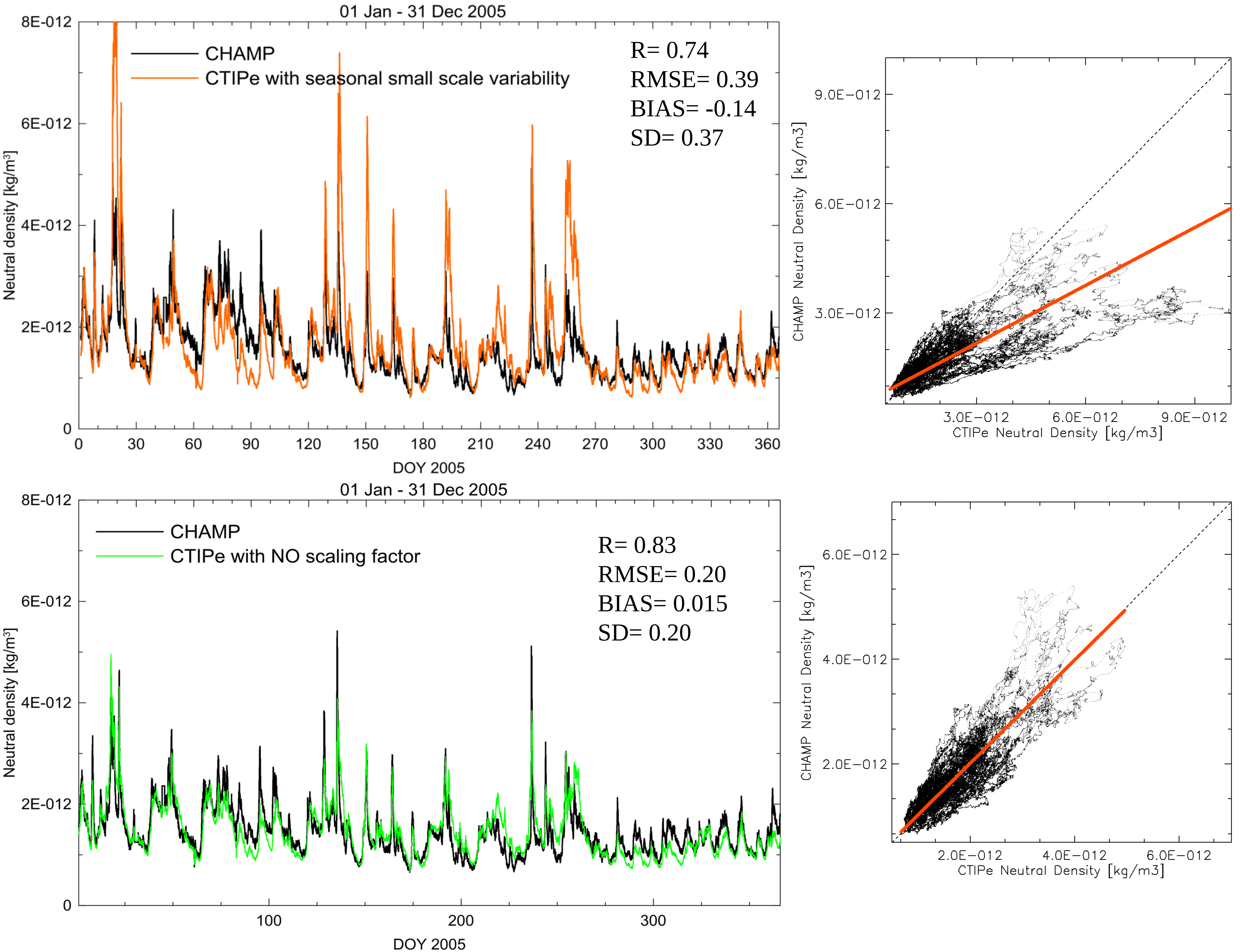


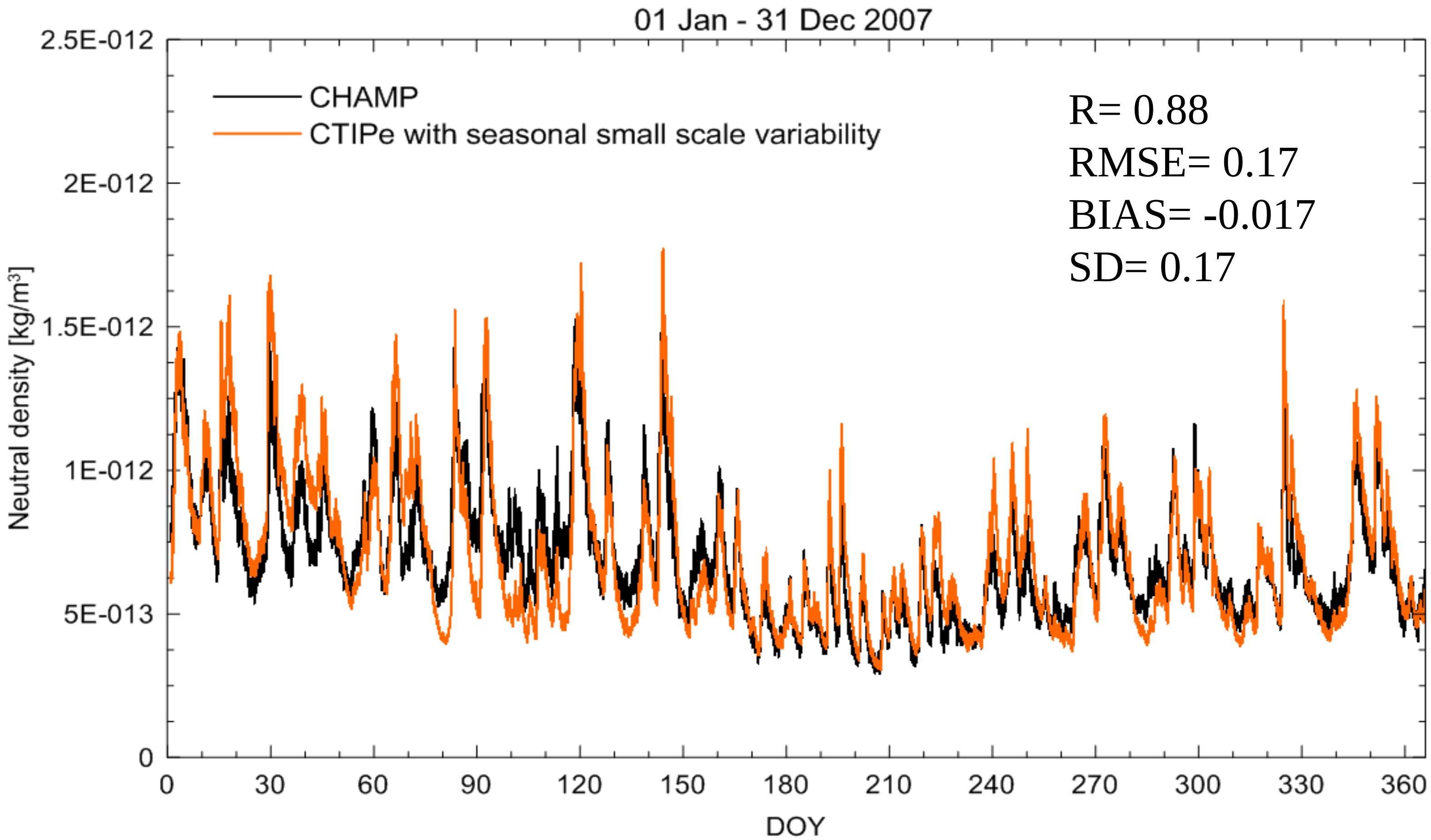


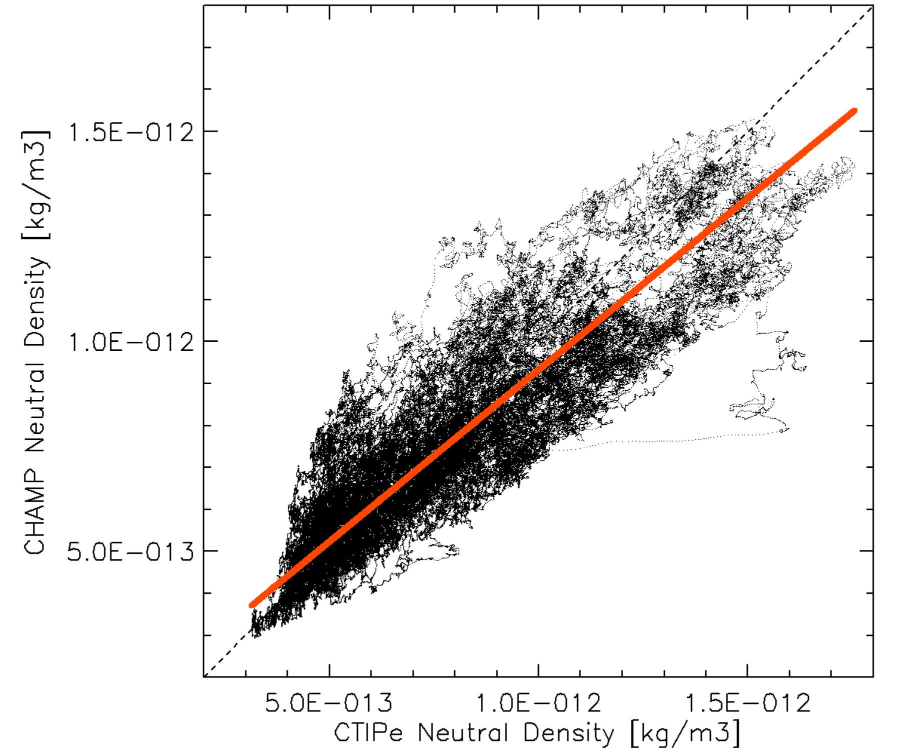


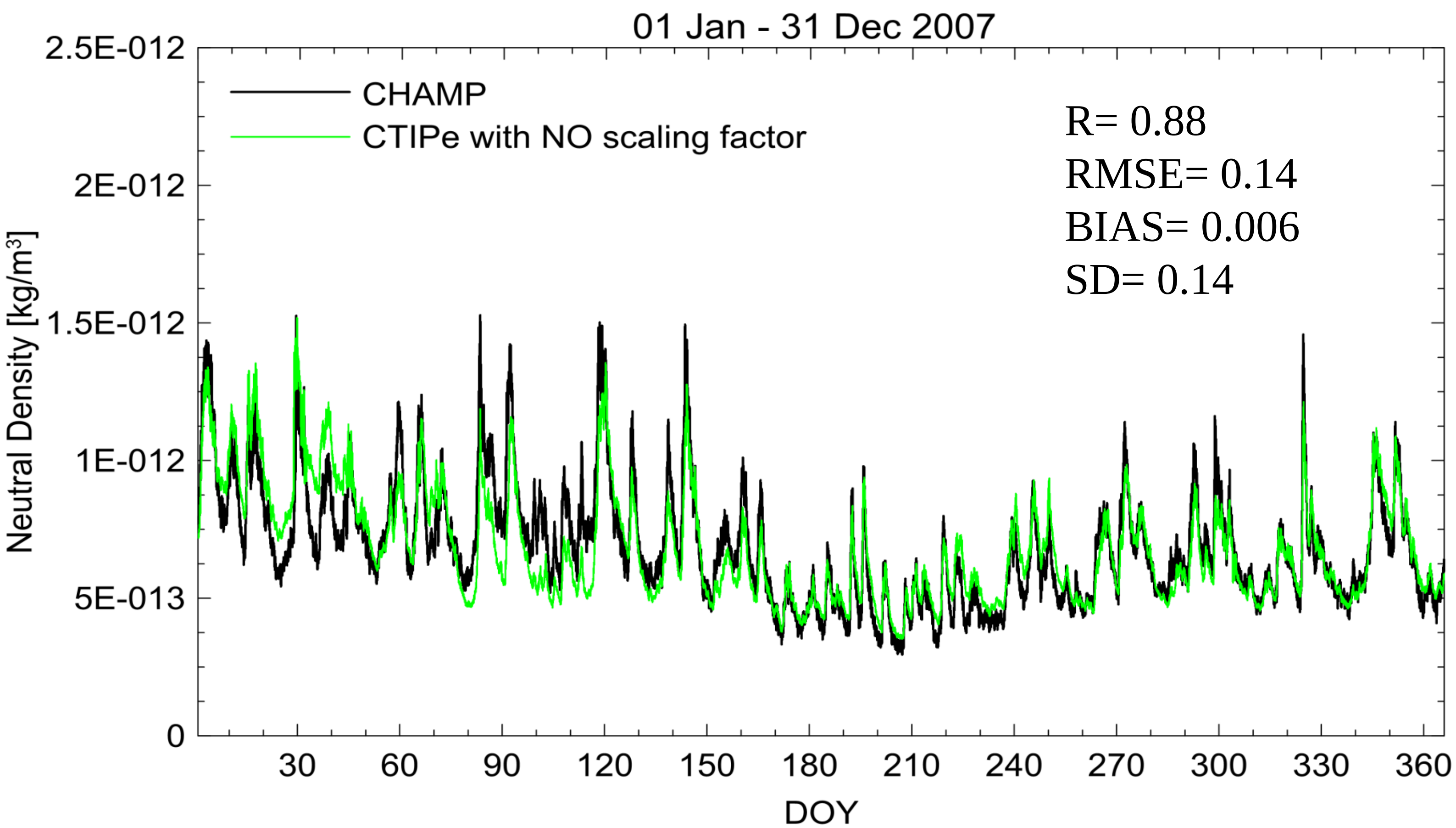
Scatter plots of daily average Kp versus principal component 1 (p1) of SNOE NO data set (Marsh et al., 2004).

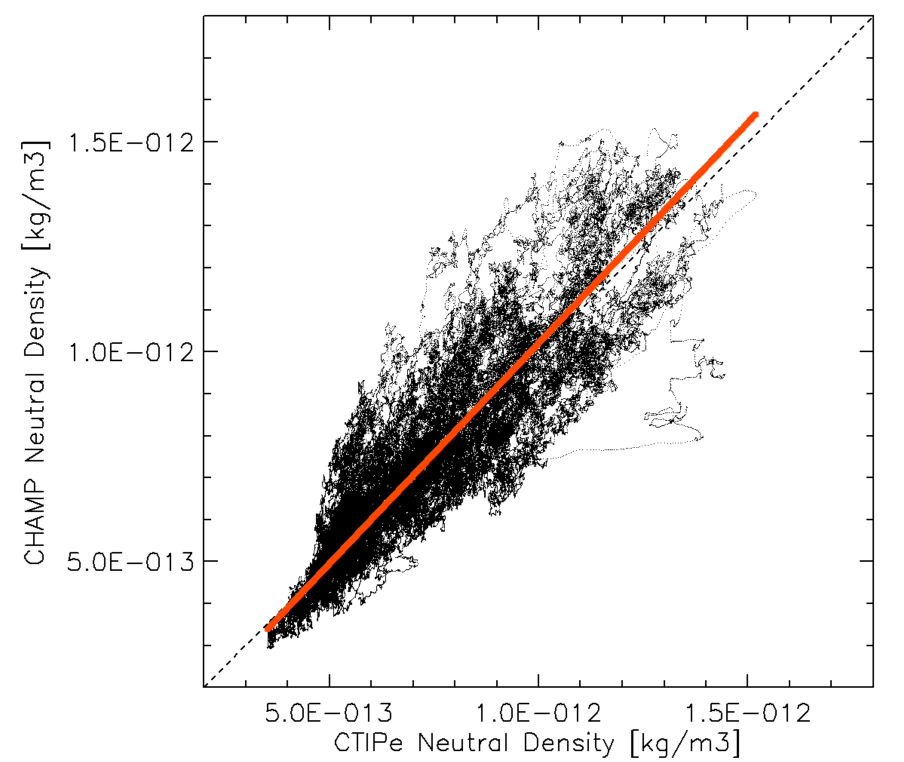
- Extrapolation algorithm using NASA TIMED/SABER satellite measurements of radiative power at 5.3µm.
- Improve the timescale for CTIPe neutral density response and recovery during geomagnetic storms.


01 Jan - 31 Dec 2005
CHAMP
CTIPe with seasonal small scale variability
R= 0.74
RMSE= 0.39
BIAS= -0.14
SD= 0.37
Neutral density [kg/m³]
DOY 2005
CHAMP Neutral Density [kg/m3]
CTIPe Neutral Density [kg/m3]
01 Jan - 31 Dec 2005
CHAMP
CTIPe with NO scaling factor
R= 0.83
RMSE= 0.20
BIAS= 0.015
SD= 0.20
Neutral density [kg/m³]
DOY 2005
CHAMP Neutral Density [kg/m3]
CTIPe Neutral Density [kg/m3]


01 Jan - 31 Dec 2007
CHAMP
CTIPe with seasonal small scale variability
R= 0.88
RMSE= 0.17
BIAS= -0.017
SD= 0.17
Neutral density [kg/m³]
DOY

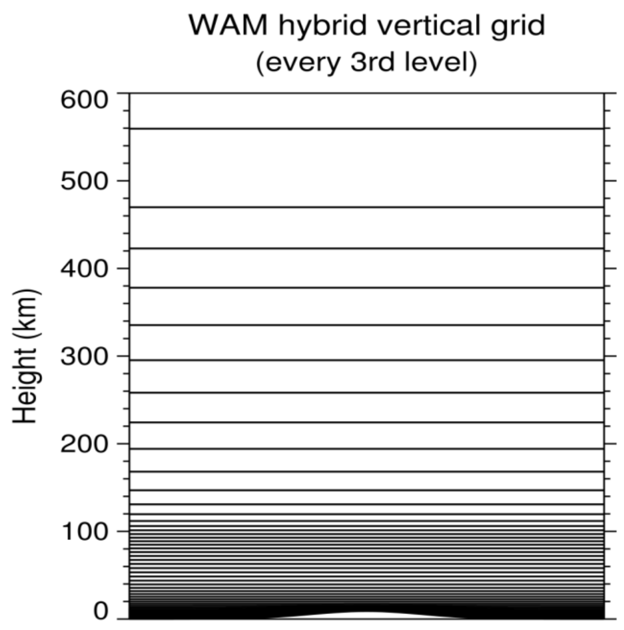

CHAMP Neutral Density [kg/m3]
CTIPe Neutral Density [kg/m3]

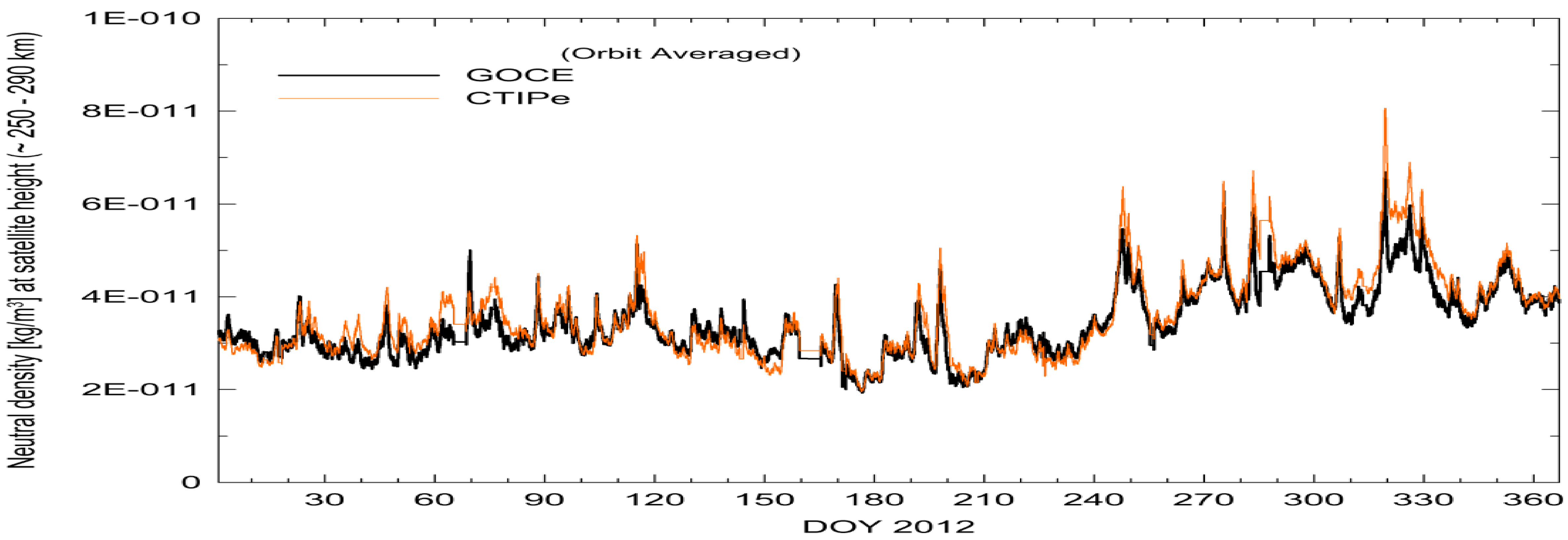

01 Jan - 31 Dec 2007
CHAMP
CTIPe with NO scaling factor
R= 0.88
RMSE= 0.14
BIAS= 0.006
SD= 0.14
Neutral Density [kg/m³]
DOY


CHAMP Neutral Density [kg/m3]
CTIPe Neutral Density [kg/m3]

Lower Atmospheric Forcing: Whole Atmosphere Model (WAM)

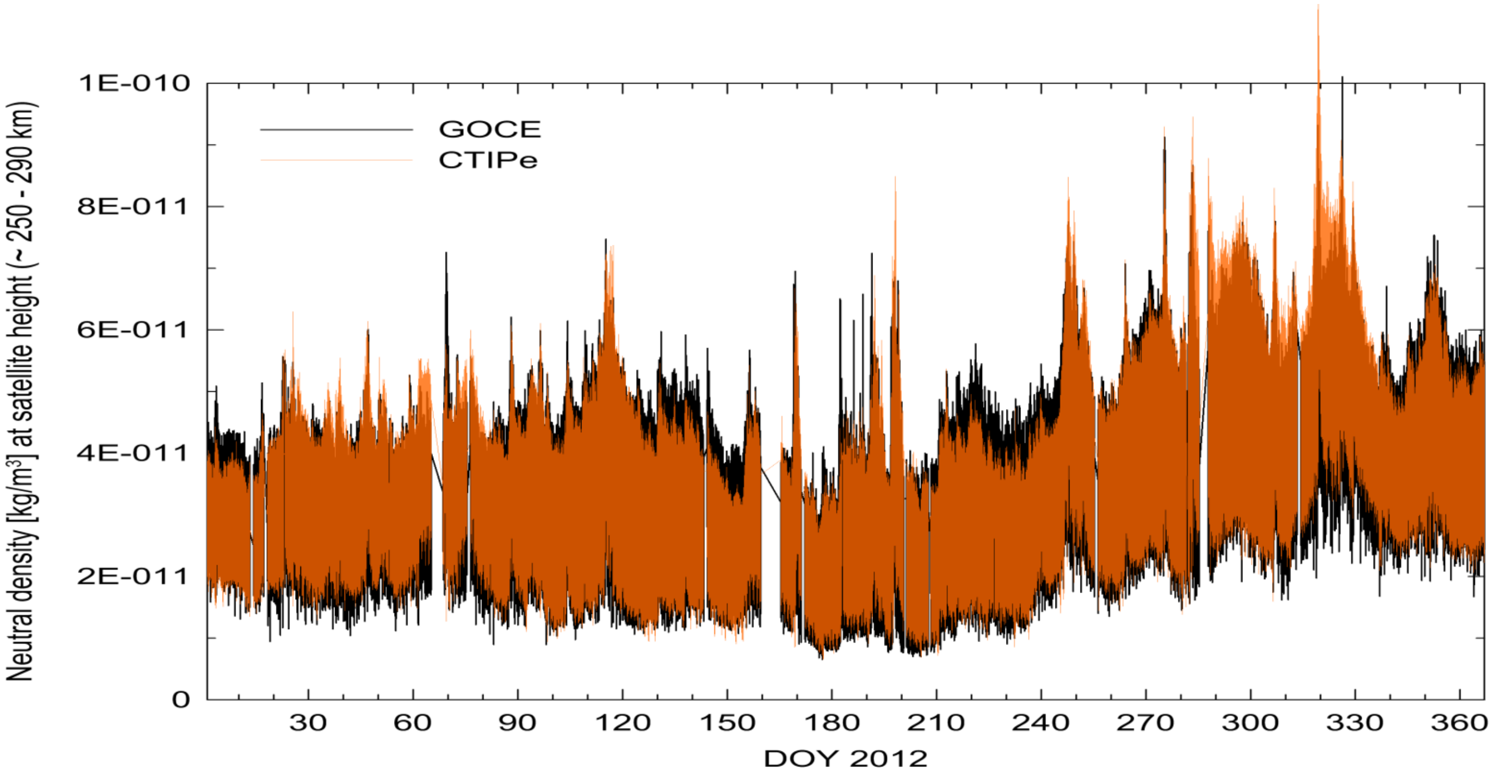
- Akmaev et al., 2008; Fuller-Rowell et al., 2011; Fang et al., 2013.
- Global seamless whole atmosphere model (WAM) 0-600 km, 0.25 scale height, 2° x 2° lat/long, T62, hydrostatic, 150 levels, 10-fold extension of Global Forecasting System (GFS) US weather model.
- O_3 chemistry and transport
- Radiative heating and cooling
- Cloud physics and hydrology
- Sea surface temperature field and surface exchange processes
- Orographic gravity waves parameterization
- Diffusive separation, ion drag, Joule heating, etc.

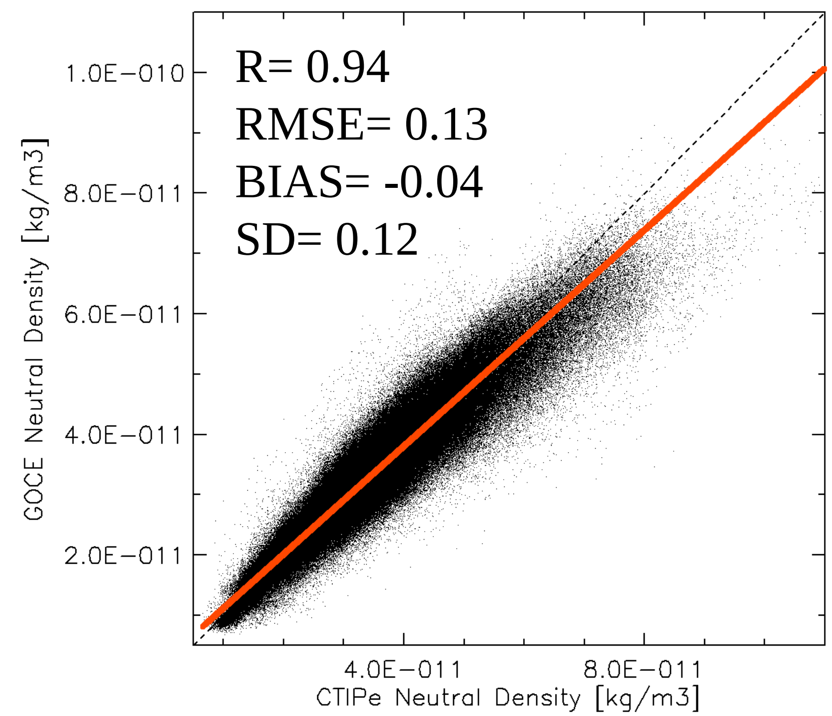


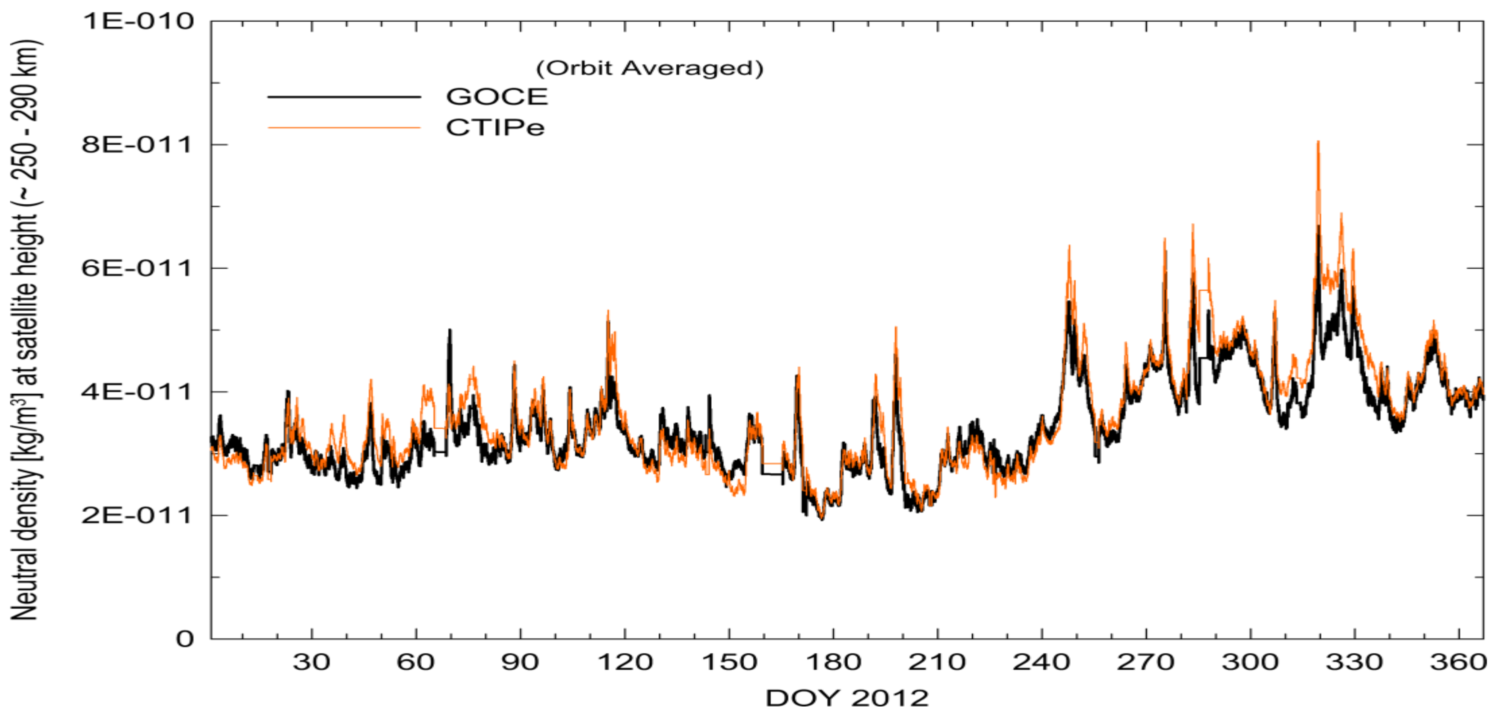


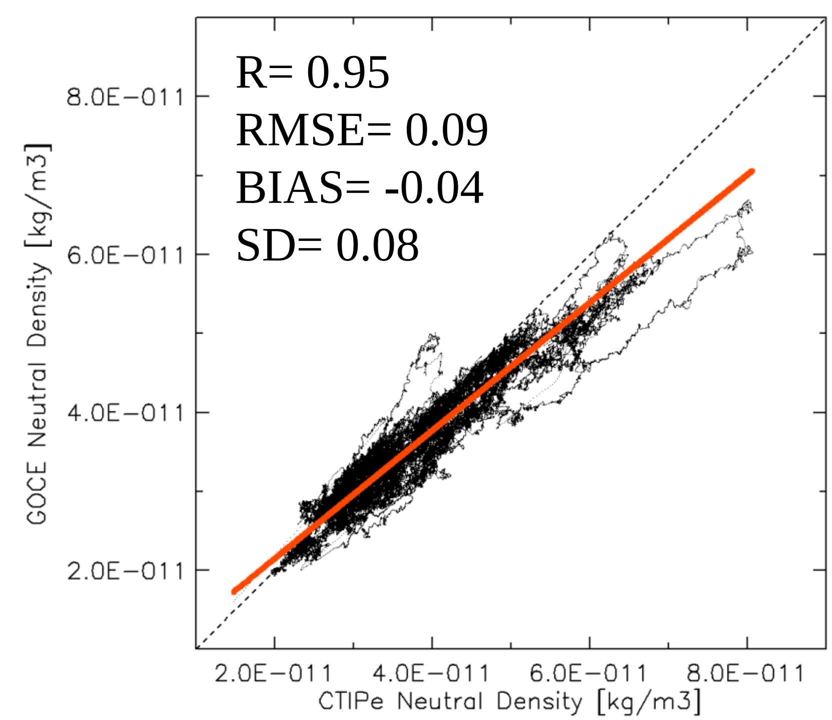
GOCE data provided by Eelco Doornbos and Sean Bruinsma

2012 GOCE/CTIPe Comparisons: Along Orbit vs. Orbit Averaged



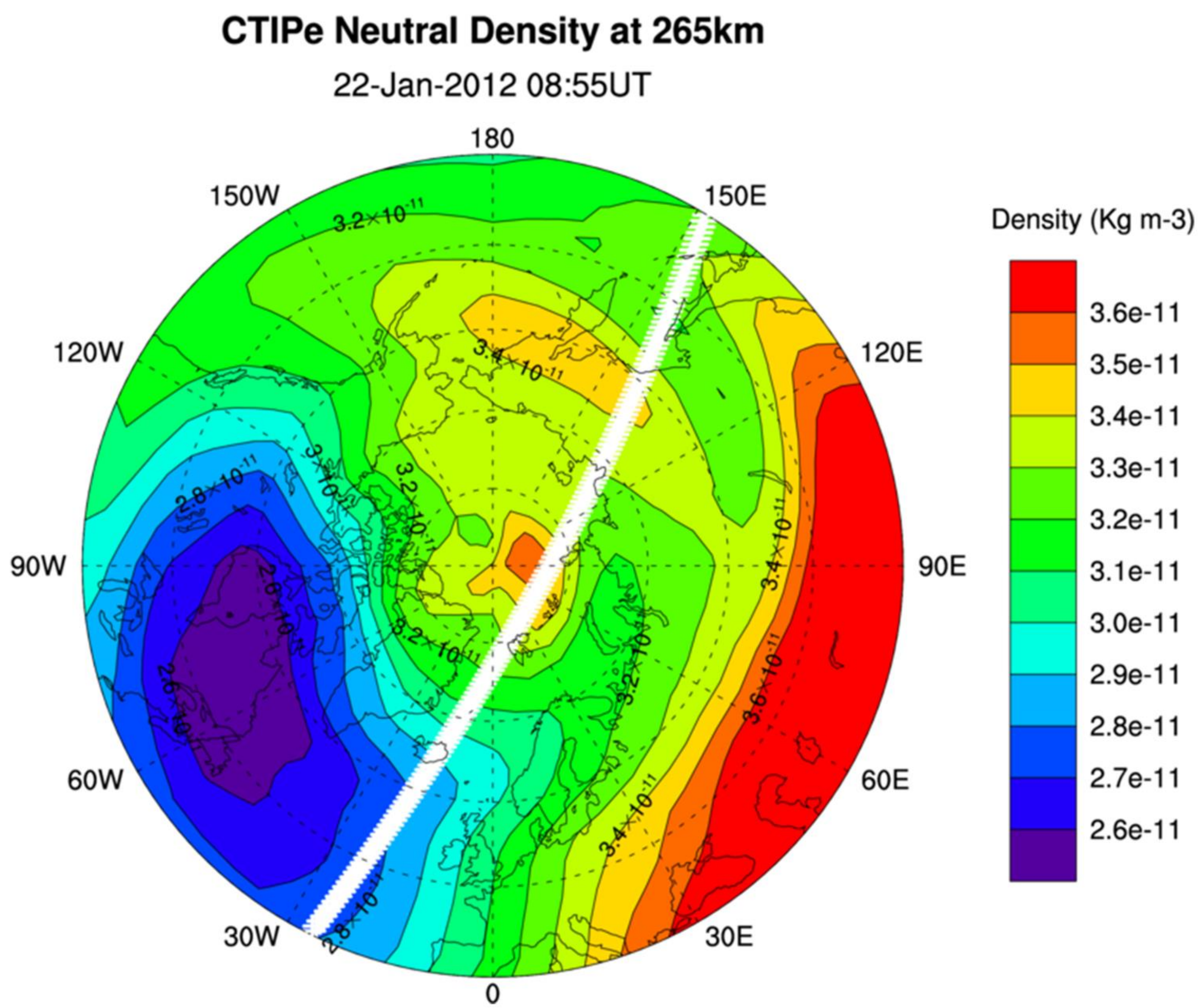


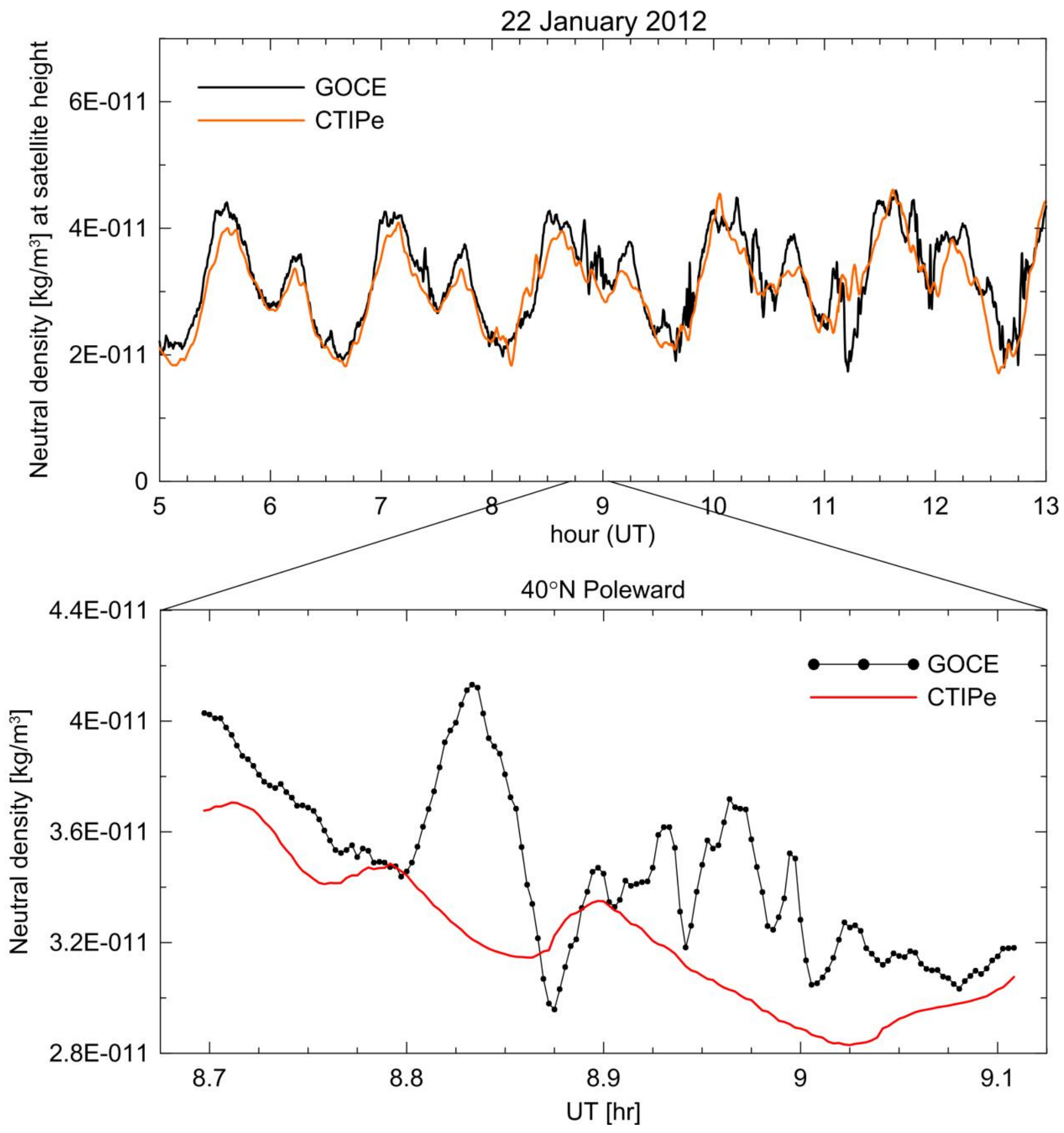




GOCE data provided by Eelco Doornbos and Sean Bruinsma

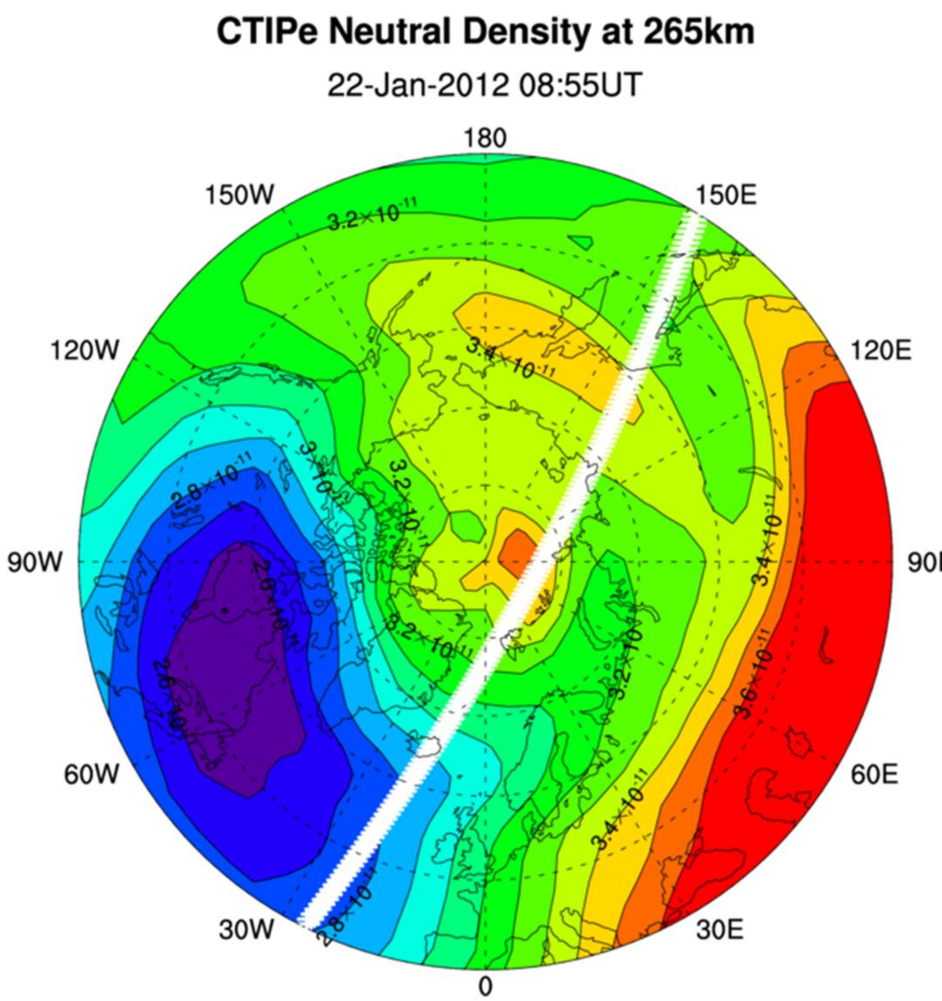
Neutral Density Spatial and Temporal Scales



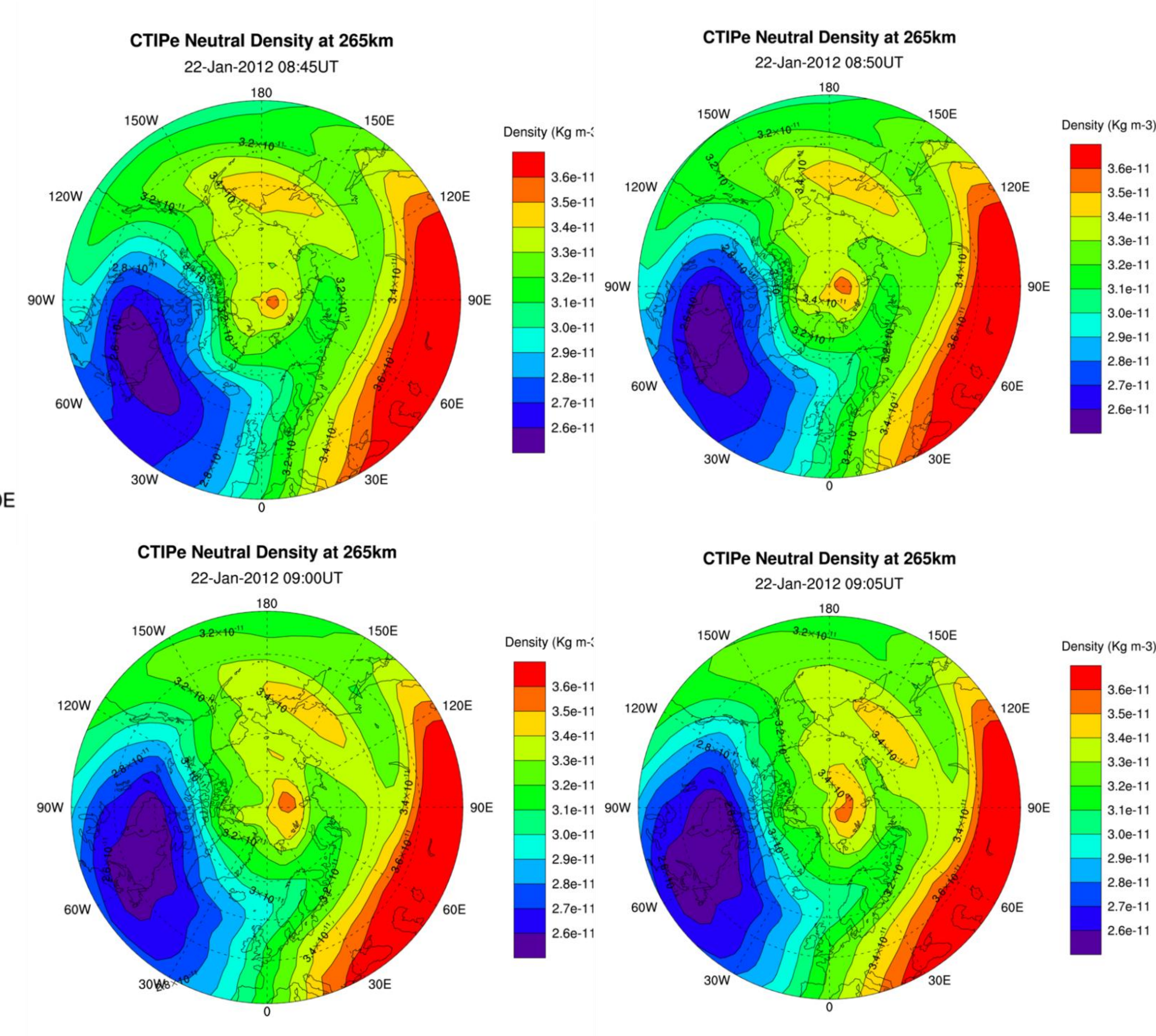


GOCE small scale fluctuations not captured by CTIPe model -> drivers, model resolution?

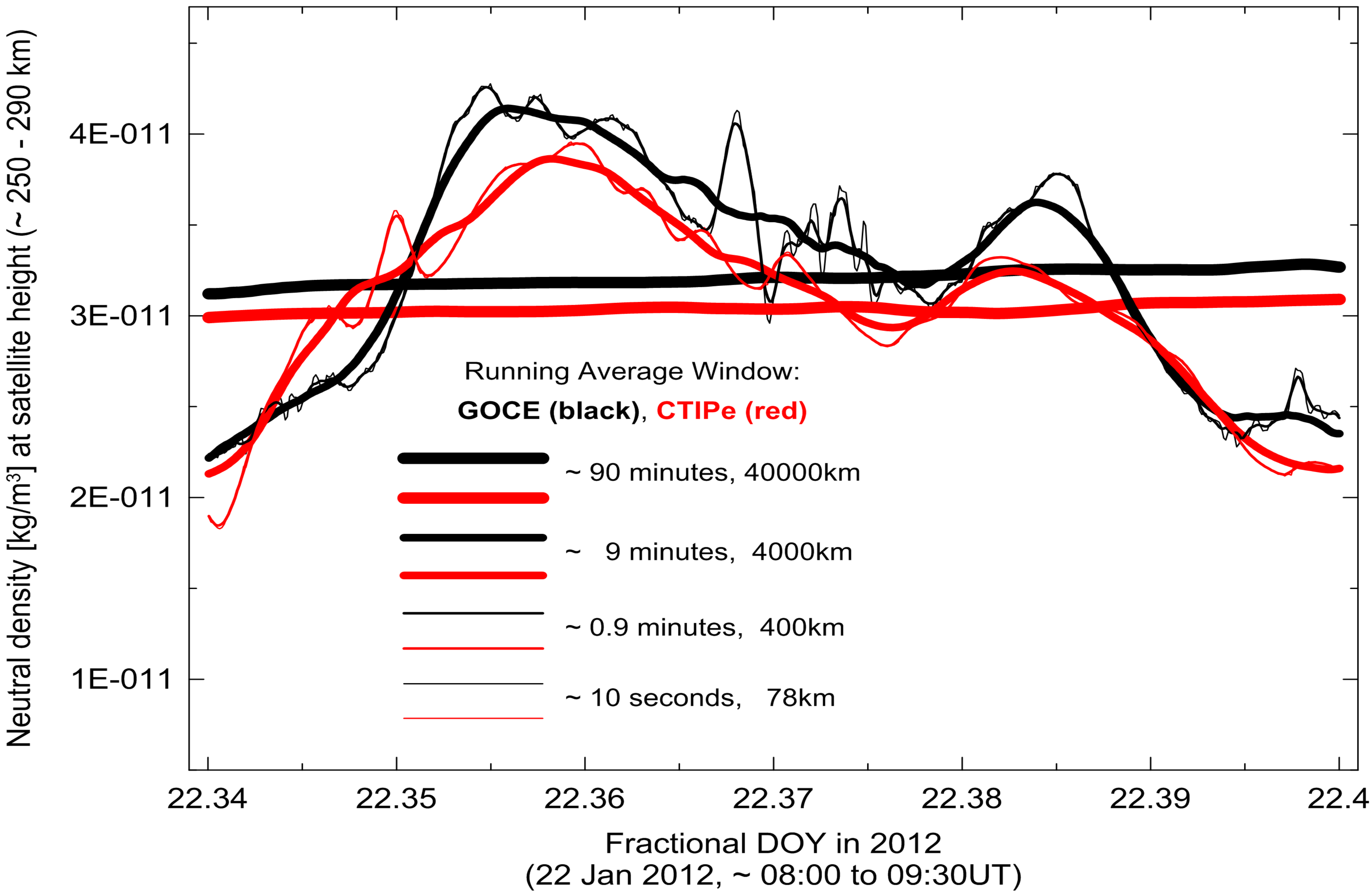
Neutral Density Spatial and Temporal Scales (cont’d)



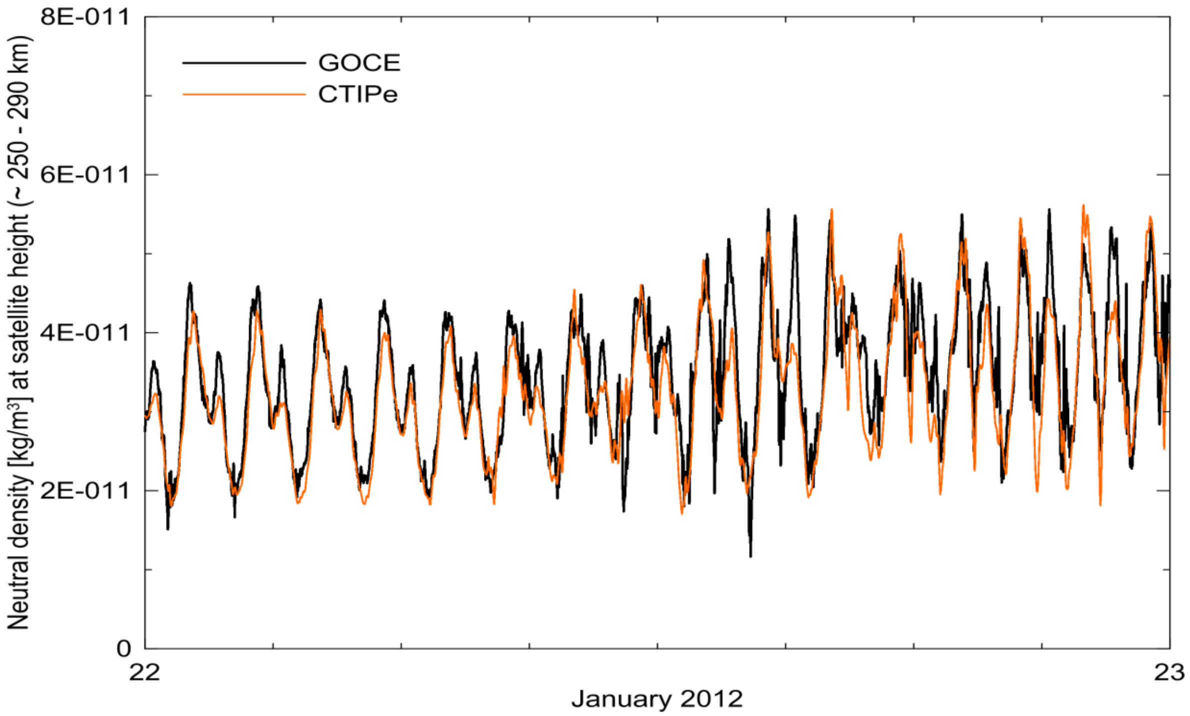
CTIPe neutral density output: 5 minutes



Neutral Density Spatial and Temporal Scales (cont'd)

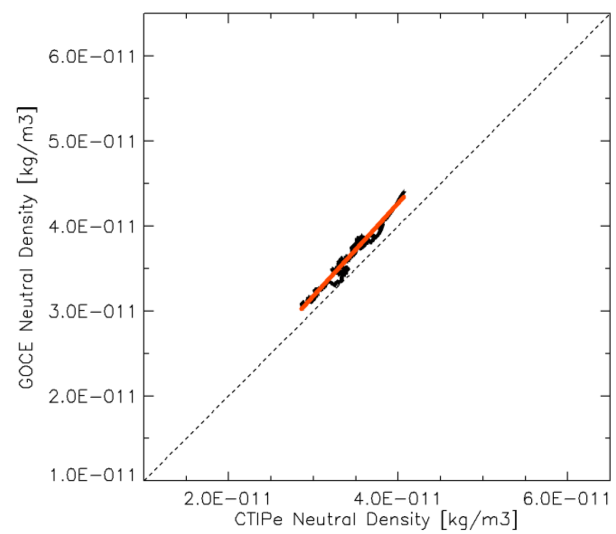


Neutral Density Spatial and Temporal Scales (cont'd)

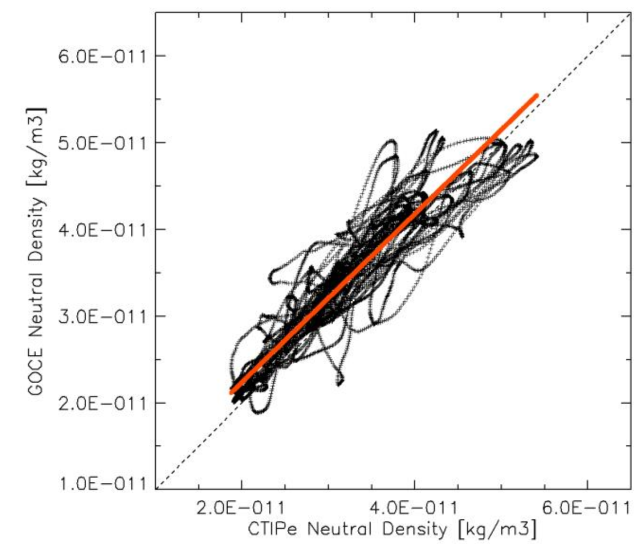


WINDOW (km)	R	RMSE	BIAS	SD
40000	0.986	0.060	0.059	0.015
4000	0.915	0.105	0.057	0.089
400	0.880	0.128	0.057	0.116
78	0.875	0.131	0.057	0.120

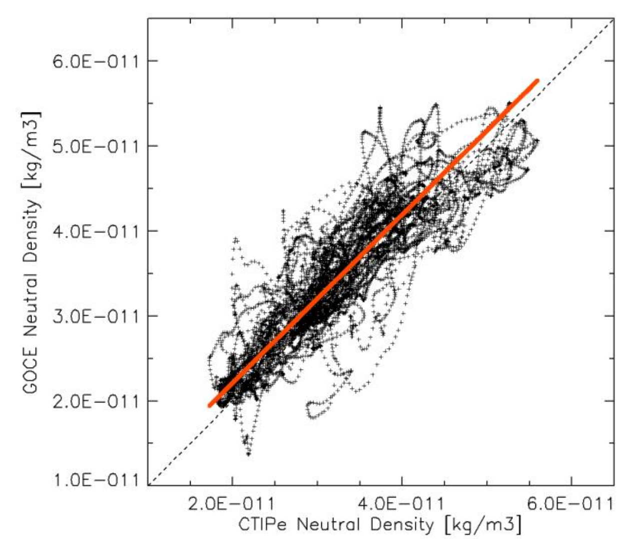
~ 90 min,
40000 km



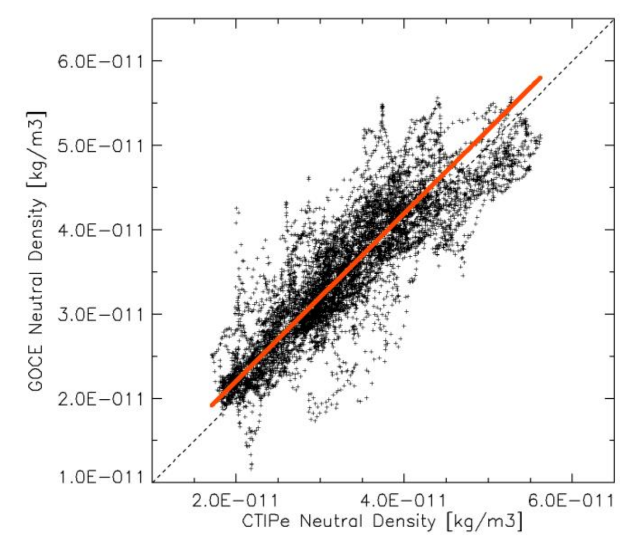
~9 min,
4000 km



~ 0.9 min,
400km



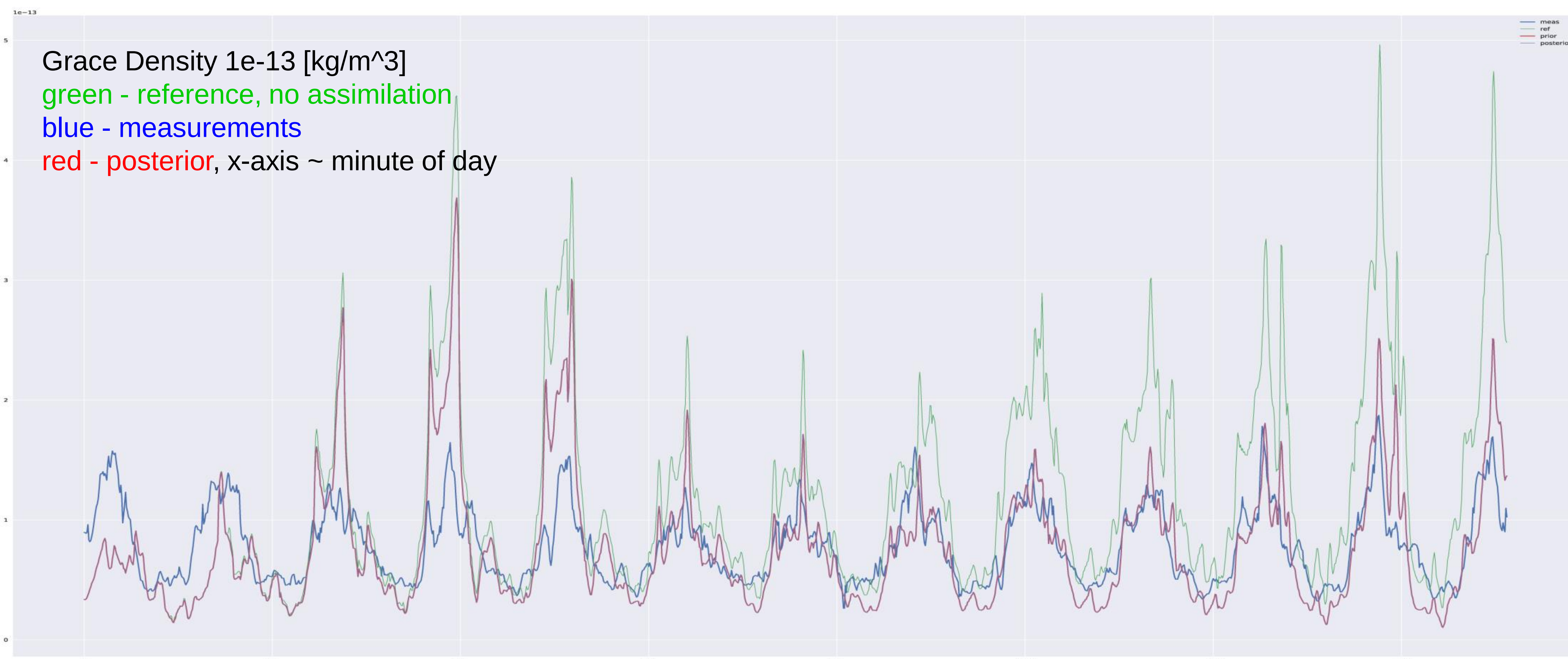
~ 10sec,
78km



Data Assimilation for the Thermosphere Ionosphere System

- Large space weather events the thermosphere and ionosphere, driven by strong external forcing and under the influence of feed-back loops, exhibit large deviations from climatology, difficult to reproduce by models.
- Successful specification and forecasting during such events requires physics based ionosphere thermosphere models and Data Assimilation (DA) schemes.
- DA in the thermosphere ionosphere system is required because of the impossibility to measure the forcing of the system with the necessary spatial and temporal resolution.

Preliminary results from the implementation of an Ensemble Kalman Filter that uses CTIPe as the background model



(Mihail Codrescu, Stefan Codrescu, Mariangel Fedrizzi)

Summary

- Thermospheric neutral density: what scale sizes are important and needed for orbit determination and why?

- How much of the model/observations discrepancies result from missing physics, model resolution, drivers?

- What other metrics (besides R, RMSE, BIAS, SD) should be used to evaluate T-I models performance?

- Models depend on data for input, validation and assimilation -> continuous measurements with good spatial and temporal coverage, and associated uncertainties are constantly needed.